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Investigation of the effects of Wax Additives On the asphalt binder

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Abstract: To reduce energy consumption and protect the environment, warm asphalt has been used widely in recent years. In this paper, Brookfield rotational viscometer test and dynamic mechanical analysis method are employed to investigate the effect of a kind of commercial wax named RH on the properties of two types of asphalt namely 60/70 and 80/100. It can be found that this kind of wax can increase the value of softening point, decrease complex modulus, and anti-rutting factor and increase the value of the penetration and the phase angle. The RH-modified asphalt has a lower viscosity, compared with the original sample.

Keywords: (WMA additive, Rheological property, Dynamic shear rheometer, Complex modulus, Rutting resistance factor)

Introduction

Asphalt is a pavement material that is brittle and hard in cold environments and soft at elevated temperatures. It has been historically employed as the most popular paving material for roadways [1]. Asphalt has been used in road construction and in many other applications for a long time. It can be produced from crude oils or found in nature as natural asphalt. The wax contained in crude oils will is still retained in the asphalt when the asphalt is produced through the distillation method. The wax may be the type of paraffin wax or microcrystalline wax. The presence of waxes in bitumen was usually considered detrimental to the performance of asphalt pavement, like increased sensitivity to cracking or rutting resistance in asphalt concrete pavements [2,3].

This was mostly based on assumption that the melting of waxes at high temperatures reduced the asphalt mixture's resistance to rutting and that the crystallization of wax at low temperatures contributed to mixture cracking. It is also considered that the wax in asphalt will lead to physical hardening and poor binder adhesion to aggregate. However, from the literature review, it can be found that many studies have been done to evaluate the effect of wax as an additive to improve the performance of asphalt mixture, and it also can be found that the effects of waxes on asphalt quality and mixture performance are reported different. With the wax additive, the viscosity of asphalt is decreased at high temperatures (above approximately 80 ℃), which improve the flow properties of asphalt.

The greatest benefit of this kind of effect is that the mixing temperature of the asphalt is reduced, and energy consumption and emissions are also reduced. Another benefit of using wax additive in asphalt is that the construction period can be extended; it has significant meaning in the cold region [3].

Paving the way for new technology. RH-WMA goes head-to-head with hot mix asphalt, steadily gaining acceptance throughout the asphalt paving industry. Over the last 5 years, numerous field validation trials of RH-WMA were established all over the world by private industry and road agencies. The successful outcome of these field trials using RH-WMA suggests that WMA using RH-WMA may eventually be considered as a standard specification option for all pavement classes once contractors and asset owners gain confidence in the long-term performance of RH-WMA. In this paper, the effect of RH WMA, on the viscoelastic properties of asphalt is investigated.

WMA is an exciting development in asphalt technology, allowing the production and placement of asphalt paving at cooler temperatures than HMA. Compared with HMA, WMA technology can significantly reduce mixing temperatures of asphalt mixture by 20°C to 30°C [4]. Asphalt pavements make up an overwhelming majority of paved roads in the world.

The predominant technology for constructing these pavements is hot-mix asphalt (HMA), and it is currently the largest end-use of energy in most developed countries. HMA has been traditionally produced at a discharge temperature between 140°C and 180°C, resulting in high-energy (fuel) costs and the production of greenhouse gases. With growing environmental concerns and ever-increasing budgetary constraints, the use of Warm-Mix asphalt (WMA) is on the rise since it addresses both issues.

WMA allows the producers of asphalt pavement material to lower the temperatures at which the material is mixed and placed on the road. Reductions of 30 to 50°C have been documented. Such drastic reductions have the obvious benefits of cutting fuel consumption and decreasing the production of greenhouse gases. Engineering and construction benefits include better compaction of pavements; the ability to pave at lower temperatures, extending the paving season; and the potential to be able to recycle at higher rates. [5, 6]. Figure 1 shows the other advantages of the technology of warm mix asphalt.

RH-WMA is a unique, cost-effective, and environmentally friendly asphalt additive that eases the mixing process by reducing viscosity and enhancing flow. RH-WMA is a polyethylene wax-based asphalt binder additive produced from cross-linked polyethylene. It is designedto reduce the viscosity of asphalt binder at high temperatures while strengthening the asphalt crystalline structure at low temperatures. Unique Advantages of RH-WMA contains most of the benefits of Warm-Mix Technology in the industry; including a reduction in production temperature without compromising pavement performance.

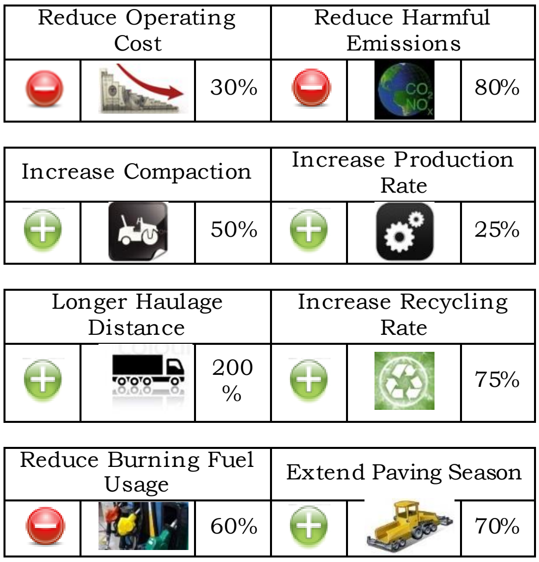

Fig. 1: Advantages of the technology of warm mix asphalt

RH-WMA can be used for all traditional hot-mix applications. With additional advantages identifiable with RH-WMA, it has been used in such demanding applications such as interstate highways, airfields, tunnels, and residential areas.

The RH-WMA additive would either reduce the viscosity of the binder or allow better workability of the mix at lower binder content. For this case, the optimum asphalt content of WMA is slightly lower than the optimum asphalt content for HMA. The Workability Index can be used effectively to assess the influence of production temperature [7]. Durability is one of the most important properties of a Hot Mix Asphalt (HMA). A key factor affecting the durability of asphalt pavements is moisture damage [8]. Moisture damage of an asphalt mixture generally called stripping potential is among the most important distresses of asphaltic pavements [9].

Cold region Asphalt pavement using rubber asphalt or stiffer binder: difficulty in compaction due to thin surface layer. Heavy traffic road that requires paving with WMA technology. Pavement construction under strict environmental controls. Reduced aging of asphalt during production to increase the service life of pavement and Pavement containing recycled asphalt pavement (RAP).

Moisture damage, occurring in several forms, can cause deterioration of asphalt pavements leading to a shortened service life of the pavement. Water or water vapour can affect the asphalt mixtures through the general `theory' of water susceptibility (sensitivity) behaviour loss of adhesion (bond) between the aggregate surface and the asphalt cement; loss of cohesion softening and reduction in strength and stiffness of the asphalt mixtures; and/or fracture of individual aggregate particles with freezing. Keeping the moisture out or at least controlling the degree of moisture in the asphalt to avoid critical levels of saturation is a fundamental requirement. Design air voids and compacted density (insitu air voids) are important factors in the permeability of the asphalt mix. Grading and nominal size can also be contributing factors. Asphalt is rarely completely waterproof so some level of moisture is inevitable [10].

Materials and methods

Two types of neat asphalt binders namely: AC 60/70 and AC 80/100 are used in this study. The basic properties of binders are shown in Table (1).

Table 1: The test results of neat asphalt.

Test properties	Unit	Test results	
		60/70	80/100
Rotational viscosity @ 135℃	(Pa.s)	0.513	0.425
$G^{*}/\sin\delta$ @ 64℃	(kPa)	1.726	1.486
Penetration (25℃, 5s , 100g)	0.1 mm	64	81
Softening point	℃	47	44
Ductility at 25°C 5 cm/min	cm	> 100	> 100
$G^{*}/\sin\delta$@ 64℃	(kPa)	3.262	2.830

RH is selected as a wax additive in this paper. RH, as a WMA additive, is a kind of white powder developed in China. RH forms a homogeneous solution with the base binder on stirring, and produces a marked reduction in the binder's viscosity. Figure 2 shows the RH-WMA that exists in the form of small white particles.

Fig. 2: RH-WMA as Additive for WMA

A Brookfield Rotational Viscometer (RV) test was used to measure the flow of binder to provide some assurance that it is fluidic enough when pumped and mixed in mixing plants and to determine the mixing and compaction temperatures. A Brookfield rotational viscometer is used to evaluate the effect of different temperatures on the viscosity after mixed with RH WMA.

Figure 3 shows the Brookfield RV that was used to determine the viscosity of the binder samples with and without RH-WMA. In this test, the temperature sweep was applied from 100°C to 170°C for PG 64 binder, at 10°C increments. For all the viscosity tests, 10 grams of asphalt binder sample was tested using spindle number 21. Three readings were taken for each test and the mean value was chosen as the final result.

Fig. 3: Brookfield Rotational Viscometer

Figure 4 shows the DSR machine used to characterize the viscous and elastic properties of the asphalt binder samples by measuring the complex shear modulus (G*) and the phase angle (δ).

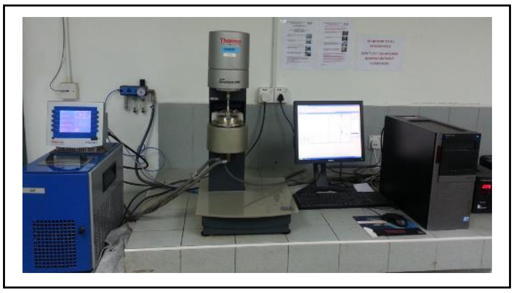

Fig. 4: DSR Equipment and Its Components

To estimate the rheological characterizations of the material, the dynamic mechanical analysis method is employed. The research of the Strategic Highway Research Program (SHRP) by the US suggests using complex modulus (G^*) and phase angle (δ) as the index of properties related to the performance of the asphalt on roads. Rheological measurements of the bitumen are performed with temperature sweeps using a Dynamic Shear Rheometer. The tests are carried out at 46–82 °C, and involved subjecting the bitumen of 1 mm thick in a pair of parallel plates of 25 mm diameter to alternating shear stress at a frequency of 1.59 Hz and measuring the resulting shear strain [11].

Results and discussion

The Brookfield rotational viscometer is used to study the viscosity properties of the binder AC 60/70 and AC 80/100 without/with RH WMA at different temperatures, both kinds of asphalt (AC 60/70 and AC 80/100) are usually used in the construction of roads. By this method, the viscosity properties of asphalt mixed with 2%, 3%, 4%, and 5% RH WMA by weight are evaluated under different temperatures. In this section, the viscosity characteristics of asphalt modified with RH are measured with Brookfield rotational viscometer when the test temperature is higher than 100 °C this step is to evaluate the workability of the asphalt mixture. The test results at temperatures 135℃ and 165℃ are shown in Figure 5 and Figure 6.

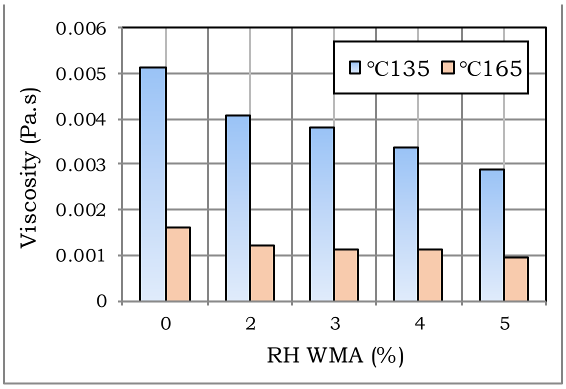

Fig. 5: The curve of viscosity–temperature for Bitumen AC 60/70

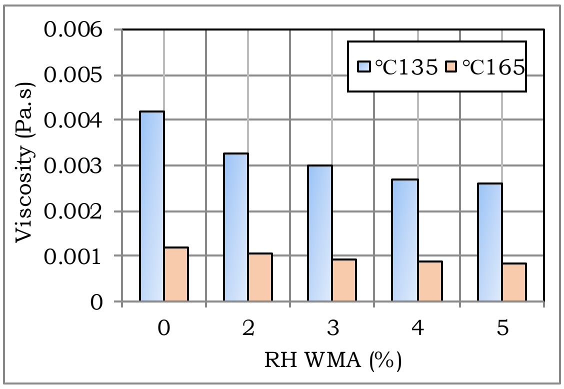

Fig. 6: The curve of viscosity–temperature for Bitumen AC 80/100

Analyzing Fig. 3 a and b it can be found that as to the two binders AC 60/70 and AC 80/100 without/with RH WMA, the viscosity decreases with temperature increasing, and when the temperature is higher than 135°C, RH modified asphalt has a lower viscosity, comparing with the original sample. It also can be found in Fig. 3 and 4 that the viscosity-temperature curve of the original asphalt is a nearly linear relationship, however, after mixing with RH, the relationship between viscosity and temperature is changed at about 135 °C, and after 135°C, the viscosity of RH modified asphalt is decreased significantly. When the temperature is higher than the entropy melting point, RH exists in asphalt as a liquid, which decreases the viscosity of asphalt. It means that RH-modified asphalt has better workability at low temperatures compared with neat asphalt.

The season that is suitable for asphalt pavement construction is short in cold regions (because the temperature is too low to construct). The properties of RH-modified asphalt make it possible to construct at relatively low temperatures, which means that the pavement construction period can be extended, which is meaningful for construction in cold regions. The mixing and compacting temperature can be determined by the viscosity-temperature curve of binders, 170 ± 20 centipoises and 280 ± 30 centipoise corresponding mixing temperature and compacting temperature, respectively [12]. The results are shown in Table (2) and Table (3).

From Tables 2 and 3, it can be found that after mixing with 2% RH, the mixing temperature and compacting temperature are decreased by about 5°C, compared with the original samples. These results indicate that the RH can decrease the construction temperature efficiently. However, this conclusion is just drawn from the viscosity-temperature curve, for some materials, such as polymer-modified asphalt, the mixing temperature and compacting temperature determined with the same method are not suitable.

Table 2: Construction Temperatures of bitumen AC 60/70 decided by viscosity–temperature curve.

Type of Bitumen	AC 60/70				
% RH WMA	0%	2%	3%	4%	5%
Mix Temp. ℃ @ Viscosity = 0.17 Pa.s	160	155	155	150	150
Compaction Temp. ℃ @ Viscosity = 0.28 Pa.s	150	145	145	140	135

Table 3: Construction Temperatures of bitumen AC 80/100 decided by viscosity–temperature curve.

Type of Bitumen	AC 80/100				
% RH WMA	0%	2%	3%	4%	5%
Mix Temp. ℃ @ Viscosity = 0.17 Pa.s	155	150	150	145	145
Compaction Temp. ℃ @ Viscosity = 0.28 Pa.s	145	140	135	135	135

To study the rheological properties of the binder after mixing with RH, a DSR test is carried out. From the DSR test, complex modulus (G*), phase angle (δ), and anti-rutting factor (G*/sin δ) can be obtained. The phase angle measured the degree of viscosity of the bitumen; the complex modulus values and anti-rutting factor reflect the ability of rutting resistance. For materials of the same complex modulus value, the one, which has a higher phase angle value, will be more susceptible to viscous deformation and the higher complex modulus values and anti-rutting factor will have a better rutting resistance. The DSR test results are shown in Figures 6, 7, and 8.

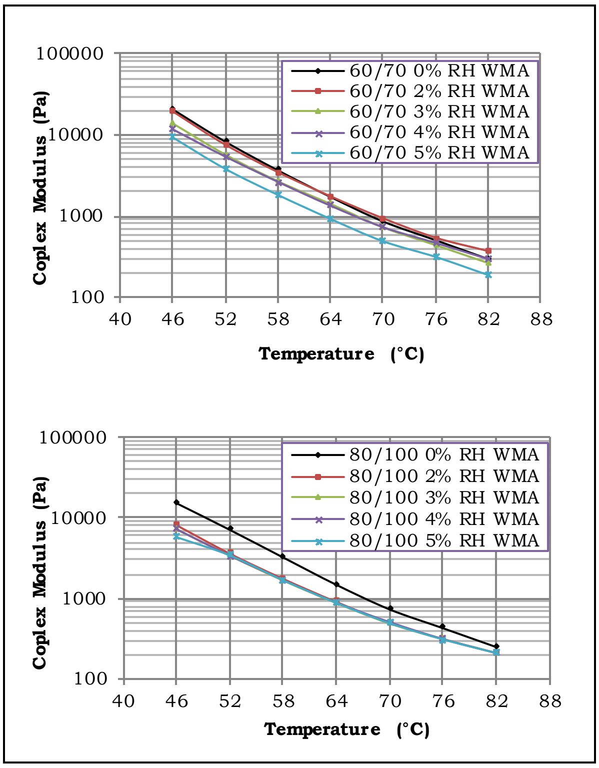

Fig. 6: The complex modulus of asphalt.

Figures 5 – 6 and 7 show the results of the temperature sweeps by the dynamic shear rheometer on the binders over the temperature range (46 – 82 °C) at the frequency of 1.59 Hz. They present the rheological behavior in graphic form for the RH-modified asphalt and original sample, respectively. In general, the original samples had relatively the highest complex modulus value and anti-rutting factor over the full temperature range.

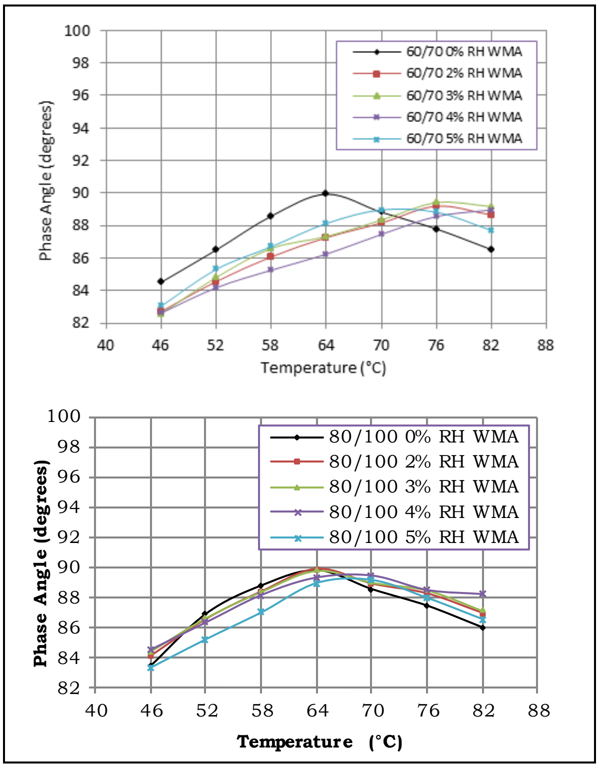

Fig. 6: The phase angles of asphalt.

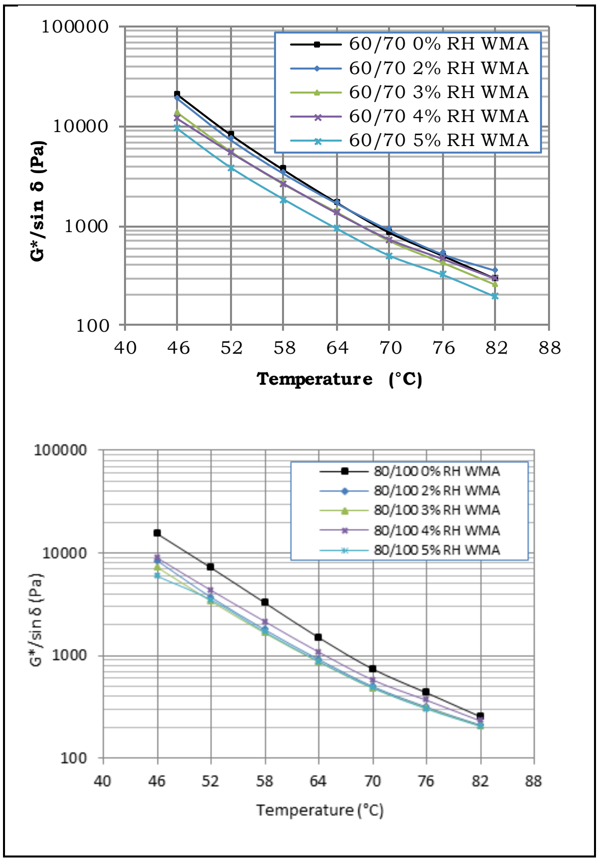

Fig. 7: The anti-rutting factor of asphalt.

From Figures 5 – 6 and 7 it can be found that with the content of RH increasing, the complex modulus and anti-rutting factor values decreased and the phase angles value increased. low binder complex modulus, together with high viscous deformation makes the asphalt pavement have low rutting resistance ability. These test results show that RH cannot improve the rutting resistance ability and decrease the temperature sensibility.

Conclusions

Based on the tests and analysis presented herein, the conclusions of the study are summarized as follows:

(1) RH additive can increase the value of softening point and increase the value of the penetration. These properties are beneficial for improving asphalt pavement rutting resistance ability. When the content of the RH additive is higher than 4%, the increased rate of penetration and the increment rate of softening point becomes slow.

(2) It is found from Brookfield rotational viscometer test that the viscosity decreases with temperature increase.

(3) RH additive can decrease the value of complex modulus, and anti-rutting factor under the temperature range (46 - 82°C). It means that RH cannot improve the temperature sensibility of asphalt. That is beneficial for improving asphalt pavement rutting resistance ability.

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